Vol. XLI. JUNE, 1899.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

No. 842.

GAUGING OF CEDAR RIVER, WASHINGTON.

BY THERON A. NOBLE, M. Am. Soc. C. E.

PRESENTED OCTOBER 5TH, 1898

WITH DISCUSSION.

In the summer of 1895 the author was engaged by the Seattle Power Company to make the necessary plans, surveys, etc., for the installation of a water-power plant on Cedar River, Washington, the object being to transmit power to Seattle and Tacoma.

At this time no authentic information as to the discharge of the river was available, except an estimate made by Mr. Benezette Williams for the City of Seattle. Mr. Williams estimated that the minimum discharge was not less than 115 000 000 galls. in 24 hours, and that the maximum discharge was about 1 500 000 000 galls. in 24 hours, which would be equivalent to 177.93 and 2 320.8 cu. ft. per second, respectively.

As the minimum estimate by Mr. Williams, the accuracy of which was somewhat doubtful, would not allow for much future extension of the capacity of the proposed plant, and as the contemplated use of water for power purposes would take most of this discharge during extreme low water, the author recommended that Cedar Lake, which is about 15 miles above the intended point of diversion and contains

1 200 acres of storage area at low water, be used as a storage reservoir to increase the flow during the dry season.

To determine the minimum flow of the river and the storage capacity available in the lake, a series of discharge measurements was made at Clifford Bridge which crosses the river about 600 ft. below the proposed point of diversion and is 12 miles above the mouth. Since September 13th, 1895, a daily record of the gauge height has been kept at the same point.

Before a current meter was purchased, it was thought that these measurements could be taken with sufficient accuracy with floats, and the calculations made by Kutter's formula. For this purpose a place was selected about 900 ft. above Clifford Bridge, where the cross-section and flow are comparatively regular for a considerable distance. The bottom of the river here contains a good many boulders, ranging from 2 ft. to 6 ins. in diameter, and the current is slow and not broken up on the surface at ordinary stages of the river. The average cross-section, wetted perimeter, maximum velocity and slope were measured for different stages of the river, and the discharge calculated by Kutter's formula, using 0.035 as the value of n. Four of these discharge measurements were taken simultaneously with meter measurements at Clifford Bridge, which made it possible to calculate the true coefficient in Kutter's formula at these two points in the river where the character of the bed is very different. The results of these calculations are shown in Table No. 1.

The few float measurements that were taken indicate that at this point there is a radical difference in the value of the coefficient of roughness n at different stages of the river. The error due to assuming 0.035 as the value of n is 48% for low stages of the river. At the highest stage measured at this point the error is only 15%, and it is probable that at still higher stages, the error would disappear.

It will be interesting to note the value of n in Kutter's formula at the point of meter measurements, which was 900 ft. below the point of float measurements, and at which the character of the river is radically different. It was impossible to obtain the slope at this point, as the river, for about 200 ft. above, is very much more rapid, and the velocity of the current at the point of measurement must be influenced considerably by these rapids. The average slope, however, was taken for some distance above and below, to take in all

TABLE No. 1.—DISCHARGE OF CEDAR RIVER. MEASUREMENTS BY FLOATS.

DATE.	Average area of cross-section.	Mean hydraulic radius.	Sine of slope.	Assumed coefficient of roughness.	Actual coefficient of roughness.	Discharge calculated by float measurements.	Discharge calculated by meter measurements.	Ratio of maximum to minimum velocity.	Percentage of error.
	sq. ft.	feet.		n.	n.	cu. ft. per second.	cu. ft. per second.		
1895.									
August 19th...	208.6	2.431	.00025	.035	.0507	246	168	.47	47
September 13th	223.5	2.500	.00025	.035	.05122	269	182	.44	40
" 6th	218	2.466	.00025	.035	.04847	260	186	.47	48
" 24th	294	3.000	.00025	.035	.03991	408	356	.55	15

irregularities near the point of gauging. The value of n, however, is not materially affected by any possible error in the slope, a change of 100% in which would make no appreciable difference. The following is a list of the values of n at the different stages of the river, as calculated from Kutter's formula:

Discharge, in cubic feet per second.	Value of n.	Discharge, in cubic feet per second.	Value of n.
103.7.....	0.037	715.1.....	0.045
147.	0.029	808.1.....	0.042
165.7.....	0.029	1 302.7.....	0.031
169.7.....	0.030	1 549.9.....	0.030
185.7.....	0.031	1 979.7.....	0.026
187.7.....	0.030	2 175.6	0.0297
356.5.....	0.040		

At this point in the river n increases with the increase of discharge, up to about 700 cu. ft. per second, and then decreases with the increase of discharge. At 1 300 cu. ft. per second the value of n remains nearly constant and is about the same as the lowest value at the point of float measurements, when discharging 356 cu. ft. per second.

At Clifford Bridge the river-bed is a comparatively even sandstone formation with no obstructions, except two or three small boulders lodged near the north bridge pier. The river flows between two rock-filled log cribs, which form the bridge piers (Fig. 1, Plate I). There was some leakage around and through these piers at very high stages of the river, but practically none when the flow was less than 2 000 cu. ft. per second. The flow at very high stages, as given in the

diagrams and tables, is more or less in error on this account and also from the fact that when the discharge was greater than 2 176 cu. ft. per second, it was estimated. Neither of these causes, however, would materially affect the discharge below 2 000 cu. ft. per second.

At the point of float measurement the stream represents a very rough condition. The boulders form eddies and side currents which must seriously reduce the effective area of discharge at low water. It would be impossible to estimate the nature or extent of this influence, which is probably nearly a fixed amount, and its effect on the discharge becomes proportionately less, as the area of cross-section increases with the height of the stream; whereas in Kutter's formula it is a constant quantity. It is evident that any assumed value of n would not give equally correct results at different stages of the river or at different places in the river at the same stage. This discrepancy is more pronounced in rapid and irregular streams, and unless the channel is very regular and the surfaces very smooth, it is impossible to obtain accurate or reliable results by surface-float measurements. The irregularity of the current in rapid streams is strikingly illustrated in the diagram, Fig. 1, in which the velocity of the current at Station 10, at the point of meter measurements, at different stages and depths of the river, is plotted. In almost every stream there are numerous side currents, eddies and irregularities in the flow, which are caused by obstacles and the unevenness of the river-bed a considerable distance above the point of gauging, which would not be accounted for in the measurement of the cross-section, etc., at the point of gauging. It is possible that, by taking the cross-section and the slope measurements for a sufficient distance along the river-bed to develop more accurately the average condition of the river, the discharge would be found to more nearly follow Kutter's formula. This, however, would make the formula very cumbersome, in many cases practically impossible to solve, and would still leave the question of the value of n to be settled.

To facilitate taking the meter measurements and soundings for the cross-section, a platform was constructed and suspended from the bridge as nearly as possible at right angles to the direction of the current and as near to the surface of the water in the river as was safe. To the up-stream face of this platform was nailed a graduated board, 6 ins. x 1 in., the top edge of which was leveled off, and projected $\frac{1}{2}$ in.

FIG. 1.

FIG. 2.

above the platform. From the top edge of this board all horizontal and vertical measurements were taken. A frame was constructed to hold the sounding rod and the meter vertically in the plane of the cross-section while the measurements were being taken. In a groove in the frame the rod or meter handle was free to move vertically in the plane of the cross-section, and the frame could be moved horizontally along the platform in the plane of the cross-section to any station desired. Fig. 1, Plate I, shows the operator with the meter and frame in position on the platform for taking velocity readings.

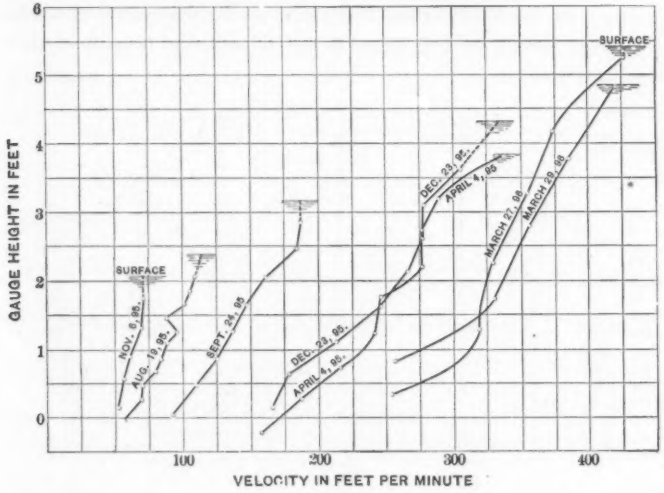

FIG. 1.

Haskell's current meter was used. The propeller wheel is 7½ ins. in diameter and is designed to make one revolution for every 2 ft. of current passing, the exact ratio being determined by rating the meter. The meter was rated twice during the discharge measurements, once over a 100-ft. course and once over a 200-ft. course. The 100-ft. course was measured on a No. 9 steel wire stretched between two piles in a favorable locality. For the 200-ft. course, the wire was stretched between the wharf and a pile 250 ft. distant. The place selected was well protected from the wind, and during the rating there was no appreciable current in the bay. Two buttons were soldered on the wire exactly 200 ft. apart. These points were used

as stations, and the stop watch in the velocity register was started and stopped while the meter in the boat was passing. The meter was fastened in a vertical position in a frame in the boat about 3 ft. ahead of the bow. The wheel was 2 ft. below the surface of the water. On each end of the boat screw-eyes were fastened, through which the wire ran and which acted as guides to keep the boat in line with the course and allow the meter to be pulled back and forth at any velocity desired. To attain high velocities a long rope was attached to the bow of the boat, and a man on the wharf pulled the boat along the course. On the 200-ft. course thirty-six velocity readings were taken, at various speeds, from 28 to 363 ft. per minute, and from these tests the meter was rated.

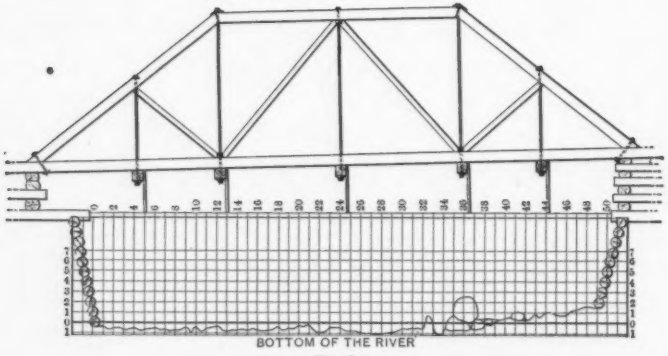

FIG. 2.

The cross-section of the stream at the point of measurement is shown in Fig. 2. Soundings were taken every 6 ins. across the stream. As the rod was always held in a vertical position in the plane of the cross-section, all the irregularities in the bed of the river at this point were accurately developed.

In taking discharge measurements the cross-section was divided into vertical sections 2 ft. wide and the full depth of the stream. In the middle of each of these sections, velocity readings were taken at depths varying from 0.2 ft. to 0.4 ft. apart (depending upon the height of the river) from the surface to the bottom. The velocity readings in each section were averaged and multiplied by the area of the section to obtain the discharge. The discharge of the river was obtained by

adding together the discharges of all the sections. In this manner discharge measurements were obtained for twelve different gauge heights ranging from 2.07 ft. to 6.26 ft., and representing from 104 to 2 176 cu. ft. per second. On account of the force of the current and the danger from floating logs, it was not safe to use the meter at higher stages of the river than the latter. The former measurement was taken at the lowest recorded height of the river, which occurred while a part of the flow was being stored in Cedar Lake during the construction of the storage dam at the outlet. These measurements are shown in Table No. 2.

TABLE No. 2.—Discharge Measurements by Meter.

Date.	Maximum velocity.	Average velocity.	Ratio of average to maximum velocity.	Area of cross-section.	Wetted perimeter.	Height on gauge board.	Discharge, in cubic feet per second.
1895.							
Aug. 10th...	141	96	.68	118.02	61	2.50	188
" 19th...	141	96	.67	105.72	60.5	2.40	170
Sept. 6th....	143	95.2	.67	116.64	61	2.49	186
" 24th....	209	140	.67	152.83	62.5	3.20	356
Nov. 6th....	105	67	.64	93.07	59.5	2.07	104*
" 14th....	131	90	.68	109.78	60.5	2.40	166*
Oct. 28th....	127	86	.68	103.37	60	2.27	1 470
Dec. 13th....	572	409	.72	318.92	70.1	6.26	2 176
" 23d....	348	220	.63	220.04	67.9	4.37	808
1896.							
March 26th..	544	403	.74	294.98	69.2	5.90	1 980
" 27th..	484	343	.71	271.40	68.5	5.42	1 550
" 29th..	452	318	.70	246.42	66.7	4.90	1 303
April 4th....	376	224	.60	191.78	64.2	3.90	715

* Taken when water was being stored in Cedar Lake.

From these measurements the stream was calibrated, giving the discharge in terms of the gauge height. The fluctuations in the discharge from August 10th, 1895, to July 1st, 1898, are shown in the diagrams Figs. 3 and 3 (*continued*). The monthly average is given in Table No. 3.

The greatest flow, 4 695 cu. ft. per second, occurred November 15th, 1896; the minimum natural flow, 138.3 cu. ft. per second, occurred October 31st, 1895. The maximum average monthly flow, 2 216 cu. ft. per second, occurred during December, 1896; the minimum average monthly flow, 163 cu. ft. per second, occurred during October, 1896. The average discharge from August 1st, 1895, to August 1st, 1896, was 846 cu. ft. per second; from August 1st, 1896,

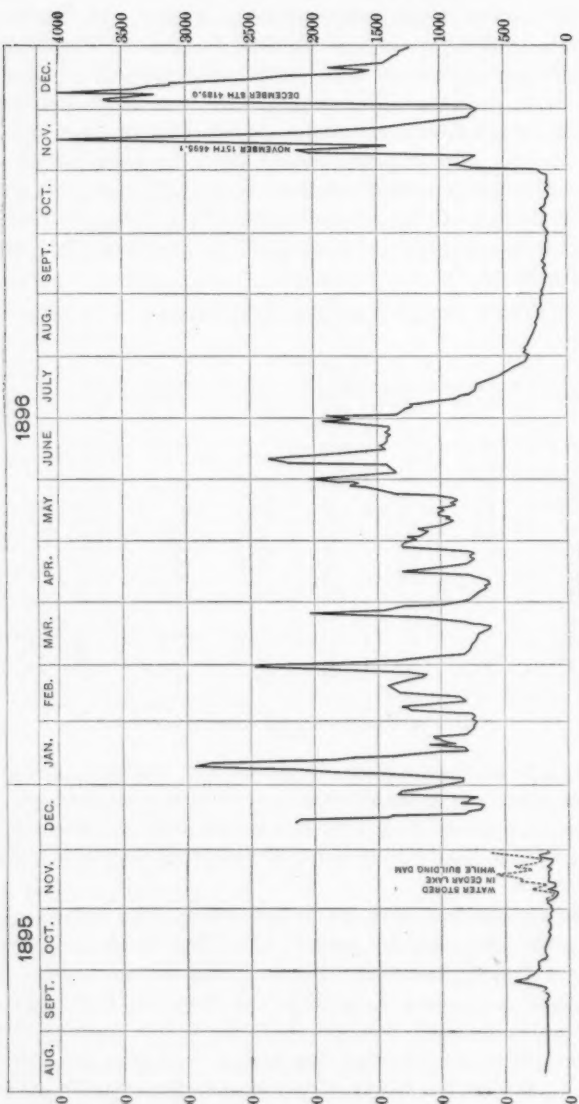
1895
1896
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
4000
3500
3000
2500
2000
1500
1000
500
0
WATER STORED IN CEDAR LAKE WHILE BUILDING DAM
NOVEMBER 15TH 4695.1
DECEMBER 8TH 4185.0

Fig. 3.

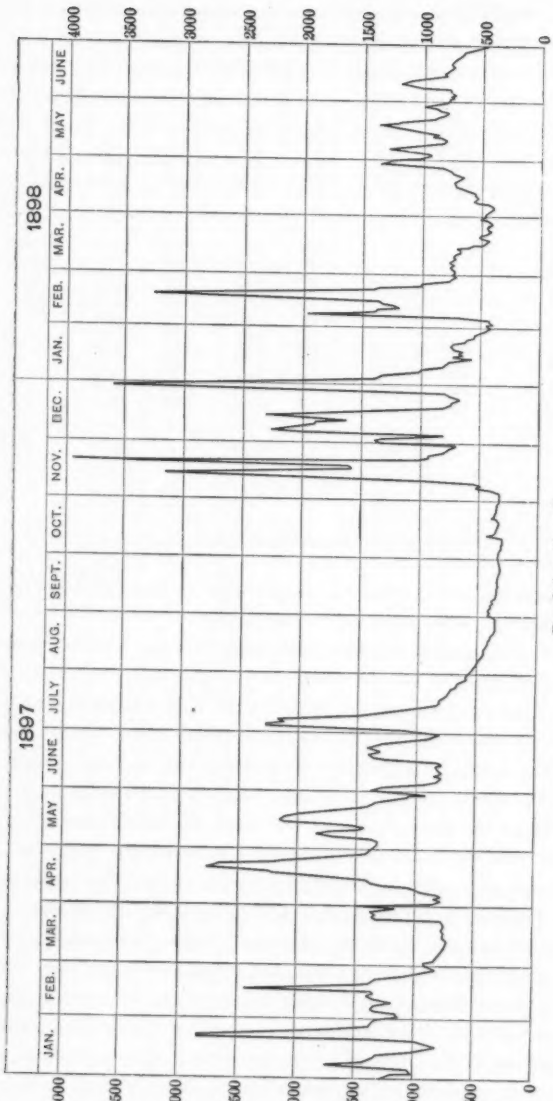

FIG. 3 (*continued*).

TABLE No. 3.—Average Discharge and Run-Off.

	1895.		1896.		1897.		1898.	
	Discharge cubic feet per second.	Run-off in inches.	Discharge cubic feet per second.	Run-off in inches.	Discharge cubic feet per second.	Run-off in inches.	Discharge cubic feet per second.	Run-off in inches.
January	.....	.....	1 318	10.56	1 454	11.42	850	6.47
February	.....	.....	1 339	10.06	1 302	9.45	1 377	10.60
March	.....	.....	939	7.53	798	6.40	587	4.71
April	.....	.....	788	6.13	1 599	12.43	716	5.56
May	.....	.....	1 284	10.32	1 562	12.55	998	8.01
June	.....	.....	1 653	12.85	1 057	8.22	801	6.23
July	.....	.....	733	5.89	1 135	9.12	.....	.....
August	193	1.55	260	2.09	448	3.60	.....	.....
September	235	1.75	229	1.78	350	2.72	.....	.....
October	172	1.38	163	1.31	339	2.72	.....	.....
November	397	3.09	1 594	12.40	1 319	10.26	.....	.....
December	1 110	8.92	2 216	18.16	1 637	13.15	.....	.....
Total	.....	16.69	.....	99.08	.....	102.04	.....	.....
Average	419.5	3.34	1 043	8.26	1 083	8.50	.....	.....

Drainage area of Cedar River = 143½ square miles.

to August 1st, 1897, 1 114 cu. ft. per second; from August 1st, 1897, to August 1st, 1898, 802.6 cu. ft. per second.

The drainage area of Cedar River has never been entirely surveyed. The upper part is in the heart of the Cascade Mountains. Two parallel ranges of mountains, spurs of the main Cascades, running in a westerly direction, form the valley of Cedar River. The mountains extend to within 10 miles of the mouth of the river on one side, and up to the mouth on the other side. Except near the summit of the Cascades at the head waters of the river, the mountains are heavily wooded with fir, cedar and hemlock. Between the summits of the two ranges the valley is from 3½ to 8 miles wide. The upper portion of the drainage area is high and precipitous, the mountains ranging from 5 000 to 8 000 ft. above sea level. Cedar Lake, which is about in the center of the drainage area, is 1 600 ft. above sea level. Fig. 2, Plate I, shows Cedar Lake looking east from the west end of the lake.

The portion of the drainage area below Cedar Lake varies in height from 20 to 5 000 ft. above sea level. The mountains in the lower portion of the valley merge into a series of high hills, which

are not precipitous. Lying between the mountains there is a considerable portion of level land, and benches which are very heavily timbered. The run off (see Table No. 3 and the diagram, Fig. 4) is calculated by assuming that the drainage area above Clifford Bridge is 143.5 square miles. This is correct except as to the upper or unsurveyed portion of the valley.

No direct information is available as to the precipitation in Cedar River valley. During 1896 a continuous record was kept at Monte

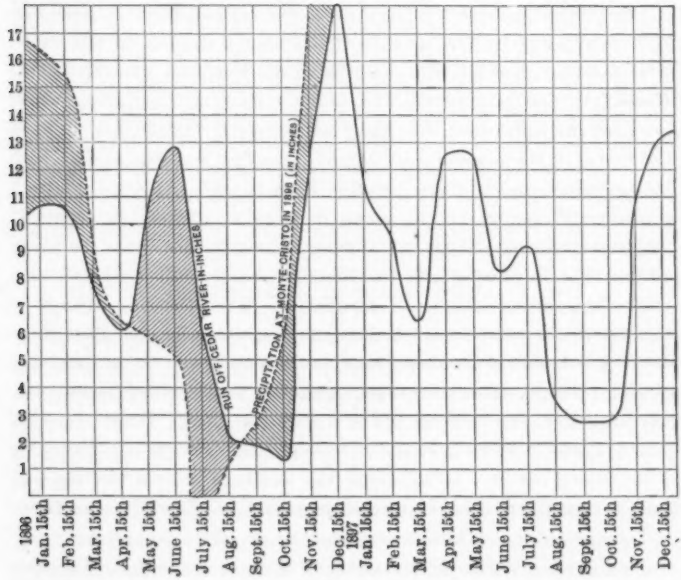

FIG. 4.

Cristo, which is 36 miles north of Cedar River, and occupies about the same relative position in the mountains as the center of the drainage area of Cedar River, and is subject to practically the same climatic conditions. In the diagram, Fig. 4, the monthly average precipitation at this point is plotted with the monthly run-off of Cedar River drainage area, to show the probable relation between precipitation and run-off in this region. During the winter months, while the snow is accumulating in the mountains, the precipitation is

very much in excess of the run-off; in the spring, while the snow is melting in the mountains, the run-off is much greater than the precipitation.

The amount of evaporation would be very difficult to determine, as the precipitation varies greatly in different parts of the basin, and innumerable stations would be required in order to get the average condition. It is not likely, however, that there is much loss by evaporation, as during most of the year the air in the mountains is near the point of saturation and the sky is overcast.

An interesting study of the influence of land surfaces on precipitation is afforded by the records of the signal stations in the Puget Sound region, between the summits of the Cascades and the Pacific Coast. In the fall, winter and early spring the prevailing winds are from the southwest, over the Pacific Ocean. At the sea coast, in the States of Washington and Oregon, they first come in contact with land surfaces, and the precipitation is enormous. At Cape Flattery and Clear Water, where the mountains reach down to the coast, it ranges from 100 to 130 ins. per annum. From the sea coast the lower air currents, in passing into the Sound country, follow the depressions between the ranges of mountains. The northern passage is through the Straits of Juan de Fuca, between the Olympic Mountains on the south and Vancouver Island on the north, and the air currents coming from the ocean over this course pass in succession in an easterly direction the following signal stations: Clear Water, Tatoosh Island, Pysht, Port Angeles and Coupeville, the latter being the center of the Sound region. In following the southern course the air currents first strike the coast between the mouth of the Columbia River and Gray's Harbor, taking a northeasterly direction around the southern end of the Olympic Mountains, and then in a northerly direction between the Cascades and the Olympic Mountains, passing in succession the following stations: South Bend, Olympia, Tacoma, Seattle and Coupeville. All these stations are at sea level and the difference in precipitation cannot be accounted for by difference in elevation. In Table No. 4 it will be noticed that the precipitation almost invariably increases from the sea coast to the center of the Sound region, at Coupeville, along the courses mentioned. From the coast of the Sound east toward the Cascades the precipitation rapidly increases again and apparently reaches its maximum at the summit. The actual

TABLE No. 4.—PRECIPITATION IN THE PUGET SOUND REGION.
MEASUREMENTS IN INCHES.

1897.	Clear Water.	Tatoosh Island.	Pysht.	Port Angeles.	Coupeville.	South Bend.	Olympia.	Tacoma.	Seattle.	Coupeville.	North Bend.	Discharge of Cedar River.
January....	16.52	12.20	8.31	8.77	2.79	8.49	5.81	6.92	3.74	2.79	10.07	11.42
February...	.....	11.16	5.19	2.17	1.82	10.30	6.58	5.19	2.99	1.82	10.05	.....
March	.....	11.31	7.86	2.40	3.49	11.24	6.29	4.73	3.05	3.49	7.65	.....
April	.....	7.61	2.75	.48	.88	3.61	1.38	1.64	1 53	.88	5.40	.....
May	.....	3.45	1.88	.03	2.18	2.58	1.02	1.46	1.30	2.18	3.86	.....
June.....	.....	3.37	1.87	1.16	.84	3.77	1.49	1.54	1.67	.84	5.33	.....
July.....	.....	3.11	.90	.88	1.46	2.19	.89	.87	2.36	1.46	3.84	.....
August....	.....	2.66	1.36	.28	.85	.86	.36	.58	.24	.85	Not given	.....
September..	3.15	2.16	1.54	1.32	1.37	2.65	2.62	1.41	2.04	1.37		.....
October	7.40	2.91	2.55	1.13	1.80	3.43	1.55	1.63	1.92	1.80		.....
November..	23.85	17.77	14.37	6.03	4.42	18.68	13.01	12.31	8.89	4.42	22.07	.....
December..	23.66	17.50	18.98	9.85	3.97	20.70	17.60	14.48	11.80	3.97	22.62	.....
Total....	.....	95.21	68.28	28.10	25.87	89.49	58.50	52.76	41.53	25.87	.....	.....
1895.....	.....	92.95	.....	24.07	.....	.....	.....	37.05	29.69	.....	.....	.....
1896.....	*102.20	100.85	.....	30.42	22.86	.....	65.46	51.02	42.83	22.86	.....	.....
1897.....	.....	95.21	68.21	28.10	25.87	89.49	58.50	52.76	41.53	25.87	90.00	.....

*Eleven months, January not included.

run-off from the drainage area of Cedar River, allowing for the loss by evaporation and the decrease of precipitation toward the lower portion of the drainage area, is greater than at any station in the Sound region at which records are kept. At the summit of the Cascades the precipitation must be very great, possibly as much as 200 ins. per annum.

It is a common belief that there is some more or less well-defined relation between the amount of rainfall and the elevation of the locality above sea level. The record of precipitation in Puget Sound is a striking illustration of the fallacy of such a supposition. At Clear Water, on the sea coast, the precipitation is greater than at Monte Cristo, which is 2 700 ft. above tide water, in the heart of the mountains directly east of Clear Water. Though precipitation in most cases is greater at higher elevations than in the adjacent valleys, it would not be safe to apply this rule to all possible combinations and climatic conditions. It is very doubtful if there is any relation that would be the same for different localities or for different periods of time in the same locality. The increase of precipitation in the higher elevations

is largely influenced by the fact that the upper air currents pass over the intervening land surface high enough to be out of reach of its influence and reach the mountains in a saturated condition, thus causing the great precipitation.

The question of precipitation is not generally of much value to the practicing engineer, because of the many influences governing its amount and variation in different localities, and the impossibility of securing data which will give a reliable basis for the calculation of the actual discharge of a stream. The only excuse for touching on the subject in this paper is to bring out some features peculiar to the region about Puget Sound, which are unusual, and will perhaps be interesting as indicating the futility of attempting to establish any relation between the run-off and the precipitation.

It behooves the engineer whose work depends upon the value or character of the discharge of any stream, to determine by actual measurement the fluctuation of discharge covering a sufficient period of time to develop any unusual conditions that are liable to occur, and the longer the period of time the observations cover, the greater their value. In adjacent drainage basins, where the topography of the country and the climatic conditions are practically the same, the discharge will be subject to the same fluctuations, and it is likely that the amount of discharge will be nearly proportional to their relative drainage areas. This is quite clearly shown in a paper by C. C. Babb, Jun. Am. Soc. C. E.,* in which the average monthly discharge of the drainage areas of the Croton and Sudbury rivers are plotted on the same diagram. Even this relation, however, would not hold good if their respective areas were too large to be subject to the same climatic influences.

In reference to the discharge of rivers and streams, a most valuable service is being rendered to the engineering public by the United States Geological Survey, in collecting and publishing the results of discharge measurements of numerous streams in the United States, made by the department and by others.

No record of the discharge of a stream is of much value unless it covers a series of years, but it is very seldom that the development of an enterprise can be postponed for the length of time required to obtain the data upon which the most important features of the scheme

* *Transactions*, Am. Soc. C. E., Vol. xxviii, p. 331.

may depend. The result is that if the engineer cannot get the desired information from some reliable source, he is compelled to make estimates, and in these he can have but little confidence, for some unexpected flood or dry season is sure to come sooner or later and entirely upset his calculations and possibly cripple the value of the plant. It seems particularly fitting that the government should undertake and carry out this work, as the case is very exceptional where the engineer is in a position to take observations covering the long time necessary to secure data of much practical value.

DISCUSSION.

Mr. Hering. RUDOLPH HERING, M. Am. Soc. C. E.—When it is realized that the country of which the author writes has been but recently settled, and that very few observations regarding rainfall and stream-flow have been recorded, it is somewhat remarkable and gratifying to note that an engineer, Mr. Benezette Williams, when asked perhaps seven or eight years ago to furnish a plan for providing the city of Seattle with water, came so near to estimating the actual minimum flow of the Cedar River, as it has now been determined by gauging. This shows what an engineer in a new country can do toward getting comparatively near to the actual facts, when the true value and importance of the few available data are carefully scanned, weighed and applied to the locality where the new work is to be done, largely on the basis of the relation between the stream-flow and rainfall in other parts of the country where this relation is more accurately known. Mr. Williams estimated the minimum flow of the Cedar River, in round numbers, at about 178 cu. ft. per second, while the gaugings of the author later determined it, as the average monthly discharge for October, 1896, to be 163 cu. ft. per second, which is certainly a remarkably close agreement, under the circumstances.

In reference to the diagram, Fig. 3, attention may be called to the act, known to the speaker from his own experience, that the minimum rainfall and stream-flow of that country for a period extending over many years appears to have occurred in 1895, the year with which the diagram begins. There was not much rainfall in the subsequent winter months, and consequently the flow in the following summer was just about as low as it was the year before. Then came a high spring rainfall, and a greater summer flow. During 1898, there was, in the early months, March, April and May, a very low rainfall, and the diagram ends at the most interesting point, namely, at the end of June, when the line still goes down, and apparently indicates that the minimum flow of the previous years may be exceeded during the fall of 1898. It is to be hoped therefore that the author, in concluding the discussion, will give the Society the benefit of the observations for the following months of July, August and September, 1898, so that a complete report of a very interesting period may be published.

It often happens that formulas are compared with actual observations which are insufficient in number and extent, and bold conclusions are drawn which are not warranted. In this case the author describes a mountainous stream, with an average depth of 2½ to 3 ft., in the bed of which are boulders ranging from 2 ft. to 6 ins. in diameter. These boulders form eddies and cause retardations which must seriously influence the effective cross-sectional area of discharge. Yet with such

conditions the author seriously applies a formula, strictly applicable only to more regular channels; and, because it does not coincide with the actual measurement, makes it appear as though the formula was not as correct as it should be. In the speaker's opinion, all the usual hydraulic formulas, from their very nature, can only be tentatively applied in such cases, because they are deduced from observations made in channels where the conditions are much more regular than those of the stream under discussion. The discrepancies which the author points out are, therefore, only to be expected. They would be reduced only by a much greater number of observations made over the particular cross-section, and by a careful consideration of the effects of every boulder or other obstruction within a reasonable distance, both above and below the section. Mr. Hering.

CORRESPONDENCE.

Mr. Le Conte.

L. J. LE CONTE, M. Am. Soc. C. E.—The apparent discrepancy between the results of gauging by the use of floats and by meter measurement can be quite easily explained. The value adopted for n was entirely too low for a stream of this class. In the case of torrential streams having a rough channel-bed composed of boulders 2 ft. and less in diameter, it is generally conceded to be unwise to adopt a velocity coefficient, for the formula $v = c\sqrt{r\,s}$, higher than 32, and in most cases where the flow is over ordinary-sized cobblestone beds, the coefficient c will not exceed 53 to 54. These values of c were found to correspond to Kutter's subcoefficient $n = 0.049$ and 0.036, respectively. The author's results would seem, therefore, to be entirely consistent with past experience in gauging such streams, namely, that as a rule the discharge is actually only about half that found by using the ordinary formulas and coefficients. Of course, meter observations are more accurate than, and superior in every way to, floats for obtaining any given discharge quantity; but, on the other hand, the floats are much more readily applied in practice, and, if good judgment is exercised, will generally give very fair results.

The method adopted by the author in gauging the flow of the rivers by simply taking gauge heights and ascertaining the corresponding discharges graphically from a previously constructed discharge curve is all very simple and makes a very convenient record; but there is plenty of room for wide discrepancies unless separate gauge heights are kept, one set for a rising river and another for a falling river, for the well-known reason that for any given gauge-height the actual discharges on a rising river are greatly in excess of the corresponding discharges on a falling river with the same gauge height. Hence, unless all the circumstances of the case are fully known and understood, the simple gauge heights have no great value in determining discharges of rivers.

The rainfall and run-off diagram, Fig. 4, page 11, is certainly quite extraordinary, the annual rainfall taken from the diagram footing up to 103.3 ins., while the annual run-off = 100 ins., or 97% of the rainfall, thus leaving practically nothing to be credited to evaporation, absorption and percolation, which generally get away with 50 per cent. The minimum daily run-off, 138 cu. ft. per second from 143.5 sq. miles of water-shed, means nearly 1 cu. ft. per second from each square mile, which, all things considered, seems to be quite anomalous.

Engineering history shows that rainfall and run-off records constitute a most valuable and reliable guide for the judgment of the hydraulic engineer. Local information peculiar to each district is, of course, especially desirable.

Table No. 3, page 10, calls to mind the fact that grave mistakes are

too often made in storage schemes based on average annual rainfall and run-off. Such calculations are nearly always misleading and fallacious, because the promotors almost invariably fail to recognize the important fact that it is utterly impracticable to catch and hold the excessive run-offs, which must run to waste, and these are the very ones which go to swell the record of the average annual rainfall upon which all the storage calculations are based. Mr. Le Conte.

GEORGE W. RAFTER, M. Am. Soc. C. E.—The paper raises a number of questions of considerable interest to every engineer having to do with the run-off of streams, which the writer wishes to discuss briefly. Mr. Rafter.

In the first place it is desired to emphasize the fact that a current meter gauging does not admit of such accuracy as to justify stating the mean monthly run-offs to even the first decimal place. The lack of judgment which engineers frequently display in the use of decimals to the third or fourth place, when the first place is ample, goes far to substantiate the view held by many people that engineers are not business men; and the use of the first decimal place in uncertain cases, where the even quantity is ample, is equally bad. The working engineer is, first of all, a man of affairs, and should not attempt to appear extremely accurate by the use of decimals, in cases not admitting of decimal accuracy.

In this paper, independent of current meter gaugings, the uncertainty existing as to the relation between run-off, precipitation, and catchment area, easily indicates large room for error. At the same time the writer does not wish to be understood as criticising the paper, either unkindly or captiously. It is rather his desire to take the paper as a text for presenting certain broad propositions in relation to stream flow and allied subjects.

It is becoming quite popular to say that evaporation is very difficult to determine—the average engineer drops the whole subject at this point—and, while the essential truth of the statement cannot be gainsaid, it is equally certain that a good deal can be done with evaporation data, if due regard is given to all that is known on the subject.

As to the view expressed by the author, that it is not likely that there is much loss by evaporation from the Cedar River catchment area, because "during most of the year the air in the mountains is near the point of saturation and the sky is overcast," it may be simply pointed out that if this statement is true for any considerable period of time, then the Cedar River catchment area is apparently an exception to about all other areas thus far studied. Undoubtedly there are, in some cases, periods of greater or less extent during which evaporation is nearly *nil*, but for the entire year the account when properly balanced will always show something to the credit of evaporation. These statements are based upon an examination by the writer of a very large proportion of all the records of run-off in relation to precipita-

Mr. Rafter. tion and catchment area thus far made. It is believed that everything published in the United States has been examined, as well as many of the foreign records.

Systematic study of the English meteorological records extending over many years has shown that in the western part of the British Isles there is usually an increase of precipitation in some degree proportionate to the elevation above sea level. For that particular region the proposition is well established that precipitation increases about in proportion to the altitude above the sea. The "common belief" that this is so, referred to by the author, is probably founded on the general use in this country, up to a few years ago, of English references to run-off and precipitation data. To broadly deny such relation, as the author does in his statement that the Puget Sound record "is a striking illustration of the fallacy of such a supposition," would seem to indicate unfamiliarity with the literature on the subject.

In the State of New York both conditions obtain. The Hudson River catchment area shows a higher precipitation at the mouth of the river than at its source in the Adirondack Mountains, while the Genesee River shows the opposite, namely, higher precipitation at its source than at its mouth. The writer will not consume the space necessary for pointing out why this is so, but will simply refer to his published reports on the Hudson and Genesee storage projects, where very extensive tabulations of the meteorology of these two catchment areas may be found.

The author's statement that "the question of precipitation is not generally of much value to the practicing engineer, etc.," must also be considered somewhat *outre*. No engineer can afford to overlook the three elements needed before questions of stream flow can be discussed properly, *i. e.*, run-off and precipitation for a series of years, and area of the catchment basin. The author is right in assuming that run-off is the most important of the three, but wrong in making excuses for introducing precipitation data.

The author, having studied rather unusual conditions, is disposed to say that any attempt to establish the relation between run-off and precipitation must be futile; and here, again, the writer thinks he has hardly done himself justice. If such a statement means that no broad general formula, covering all classes of streams, is ever likely to be found, then he is undoubtedly on sound ground. If, on the other hand, he means to assert that no formula can be made to fairly fit a given catchment area, then it is equally clear that he has not familiarized himself with what has already been done in that direction.

As a matter of fact, precipitation has its definite laws as well as everything else in the universe, and engineers interested in stream flow questions ought to understand the general trend of such laws. The writer, however, does not wish to be understood as saying that all the

laws governing rainfall apply with equal force to widely separated localities. That some of them do so apply, may be gathered by perusal of a paper, "On Mean or Average Annual Rainfall, and the fluctuations to which it is subject,"* by Alexander R. Binnie, M. Inst. C. E. In this paper Mr. Binnie shows, by an analysis of a large number of precipitation records from different parts of the world, that there are certain fundamental laws applying to precipitation which are about as well established as most of the laws of physics. Mr. Rafter.

Mr. Binnie's paper may be referred to for illustrations of certain well-established laws of precipitation applying to all parts of the world. As an example of fairly well worked-out laws of precipitation, which are not considered as applying to other than a specific drainage area, reference may be made to the writer's report on the Hudson River storage.† Without being exhaustive, it is believed that these two references will furnish enough data to establish the fact that the present state of knowledge of the laws of precipitation is not chaotic.

BENEZETTE WILLIAMS, Esq.—While to those interested in hydraulic gaugings and hydraulic formulas there is much in the paper deserving of thorough discussion, yet the reference to the writer's estimates is scarcely of such nature. It may be well, however, to correct any conclusion which the readers of the paper may form, to the effect that the writer made a gauging of Cedar River. This he did not do. What he did was to estimate the probable discharge of that river, based upon surveys of the slope, and cross-sections, and the observed height of water at three different stages, made by the city engineers of Seattle. The maximum and minimum discharge, stated in the paper as originating with the writer, were evidently taken from his printed "Report on Water-Works for the City of Seattle, to the Mayor and City Council," February 28th, 1890. Mr. Williams.

The following extract from the report itself will convey the best idea of what the writer did with reference to determining the flow of Cedar River:

"There has been no opportunity for a careful hydrographic survey of the river, but such as came incidentally in the course of the preliminary work.

"From the cross-sections of the river-bed, the slope of the stream, and the height of water at different stages of the river, I estimate that on December 21st, 1889, before the snows began to melt, and when the river may be considered as being not much above its low-water stage, the flow was 115 000 000 galls. in twenty-four hours. During February, while the snows were melting, one stage showed 675 000 000 galls., and some days later, at still another stage of the river, probably near the high-water stage, the estimate gives 1 500 000 000 galls. in twenty-four hours. These estimates are rough, and should only be used to indicate the fact that the amount of water that can be furnished by the river, used in connection with Swan Lake as a storage reservoir, will be ample for all possible demands that the city can make upon it."

* *Min. Proc. Inst. C. E.*, Vol. cix, p. 89.

† "Annual Report of the State Engineer and Surveyor of the State of New York, 1896."

Mr. Williams. From the above it is seen that the minimum of 115 000 000 galls. in twenty-four hours, or 177.9 cu. ft. per second, was the estimated flow of the river at a stage which was thought to be "not much above its low-water stage." The author erroneously states that the minimum discharge, as estimated by the writer, was "not less than 115 000 000 galls. in twenty-four hours." His statement that the writer estimated the maximum discharge to be "about 1 500 000 000 galls. in twenty-four hours," is, perhaps, not so much astray, though, as a matter of fact it is quite different from the language of the report, which says that at a certain stage of the water the estimate was 1 500 000 000 galls. in twenty-four hours, and at this time the river was "probably near the high-water stage." Such language, qualified by the subsequent warning that the "estimates are rough, and should only be used to indicate the fact that the amount of water that can be furnished by the river, taken in connection with Swan Lake as a storage reservoir, will be ample for all possible demands that the city can make upon it," hardly warrants the use of the figures as a determination of the maximum flow. The facts are that the extreme high-water flow of the river had no place in determining the questions in hand, and the assumption that at the particular stage mentioned the river was near high water was based upon a general and unverified statement by the surveyors who did the work. All the engineering work upon which the report was based was done between the latter part of October, 1889, and the latter part of February, 1890, or in less than four months.

To search out a pipe line running 30 miles into a Puget Sound forest, and to make other necessary explorations at that season of the year (when more than half the days are given over to rain or snow) with the force at command, did not permit of much useless work.

The estimates of flow given were based entirely upon the functions of slope and cross-section, with an assumed value for n in Kutter's formula; the slope being assumed constant for all stages of the river. The original data or figures not being at hand, the value used for n cannot now be given.

It may be interesting to compare some of the figures thus obtained with the author's more elaborate determination extending over a period of three years. He found the minimum natural flow, based upon current-meter measurements, as the writer understands it, to be 138.3 cu. ft. per second. The writer estimated that on December 21st, 1889, when the river was considered as being not much above its low-water stage, the flow was 177.9 cu. ft. per second, a difference of a little more than 28 per cent. The author's measurements made by floats were from 40 to 48% greater than his meter measurements when the river was near its low stage. To all appearances this would bring the low-stage determination by the method used by the writer between the float and meter measurements made by the author.

Other determinations by the author are of interest as bearing upon the value of elaborate and involved formulas, such as Kutter's. His statement that "the error due to assuming 0.035 as the value of n is 48% for low stages of the river, while, at the highest stage measured, the error was only 15%, is not reassuring as to the value of such formulas. Mr. Williams.

The tabulation on page 3 gives a range in the value of n from 0.026 to 0.045. The question arises, of what use is elaboration in a hydraulic formula if such is the case? Why is it not just as scientific to guess at c in the formula $v = c\sqrt{r\,s}$, as to guess at n in Kutter's involved equation, and also much simpler? It is safe to assert that if it were not for the disposition of so many minds to seek the truth in a maze, the simple form of $v = c\sqrt{r\,s}$ would never have been departed from, and the painstaking ingenuity that has produced so many fantastic shapes of hydraulic formulas would have been directed to determining the value of c under the varying conditions of practice, much to the advancement of the empirical science of hydraulics.

T. A. Noble, M. Am. Soc. C. E.—The author wishes to express his satisfaction with the interest shown in this discussion by those whose extended experience makes a valuable addition to the paper. It was very far from his intention to leave any impression that might cast reflection on the estimates made by Mr. Williams in his report to the City of Seattle. Mr. Noble.

In view of the data that were obtained at no small trouble and expense, covering a period of three years and including four dry seasons, it is rather remarkable that Mr. Williams should have guessed so well.

It was supposed, at the time the paper was written, that during the summers of 1895 and 1896, the river had possibly reached the lowest stage it ever would, though the comparatively small discharge during the spring of 1898 would indicate, as Mr. Hering has suggested, a still lower stage during the following summer. The experience of 1898 emphasizes with considerable force the statement in the paper that, "No record of the discharge of a stream is of much value unless it covers a series of years." The lowest point reached at Clifford Bridge, September 19th, 1898, was 72 cu. ft. per second, as against 138 cu. ft. per second on October 31st, 1895. This is such a radical difference that it becomes a matter of vital importance. The year 1898 seems to have been one of unusually low water along the whole Pacific Coast.

Though the complete record of the flow at Clifford Bridge during this summer is not available, yet the flow from Cedar Lake, the record of which is complete since July 1st, indicates that the average flow during the dry season was not much less than in 1896 on account of rains in October as shown in Fig. 5.

Gaugings and a record of the gauge height near the outlet of Cedar Lake, about 15 miles above Clifford Bridge, on Cedar River, have been kept since July 1st, 1898.

Mr. Noble. The gauge height at Clifford Bridge was kept for some timeafter July 1st, in order that, if possible, a comparison could be made with the discharge at Clifford Bridge during previous years. The two curves of low water seem to follow each other in a general way, but without much regularity. The drainage area at Cedar Lake is approximately 80 square miles, and at Clifford Bridge 143 square miles. The relative flow at the two places, from July 1st to September 19th, is shown in Table No. 5.

TABLE No. 5.

Date.	Gaugings at Cedar Lake.		Corresponding Discharge at Clifford Bridge.	
	Cubic feet per second.	Cubic feet per second per square mile.	Cubic feet per second.	Cubic feet per second per square mile.
July 1st.....	357	4.46	510	3.56
October 1st.....	243	3.04	....	....
July 25th.....	110	1.83	207	1.45
September 13th...	46	0.58	84	0.59

Comparative Discharge at the Two Places at Different Stages for the Same Area.

	July 1st.	July 25th.	September 13th.
Clifford Bridge.....	1.00	1.00	1.00
Cedar Lake.....	1.43	1.26	0.98

It should be explained that during June, July, August and September there was practically no rain, and the weather was warm over the entire drainage area. It will be noticed that the discharge gradually decreases until about the first of August, after which time the snow in the mountains being practically gone, the discharge comes almost wholly from springs and seepage. As the snow accumulates mostly in the upper portion of the area, there is a greater proportional discharge in the upper portion of the valley during the spring and the early part of the summer until the snow is gone, when the discharge for the same area becomes practically the same. There are times, however, when it is raining in the lower portion of the area and snowing in the upper portion, and then the discharge per square mile in the lower portion is likely to be greater than that in the upper portion. This ratio of discharge in different portions of the area is constantly changing, being influenced by the amount and distribution of

the rain and snow and by the temperature. At no time is the combination of these influences exactly the same, except in midsummer, when the discharge comes entirely from springs and seepage. Mr. Noble.

At times, when there is an unusual amount of snow on the ground there comes a warm wind and rain, when the run-off becomes enormous, producing floods of a magnitude unknown in any other part of the United States on an equal area.

Ignorance of these conditions has led to mistakes in practically every railroad location in the Sound country, and is now giving serious trouble to an engineer who is putting in a water-power plant in this vicinity and has located the tail race too low.

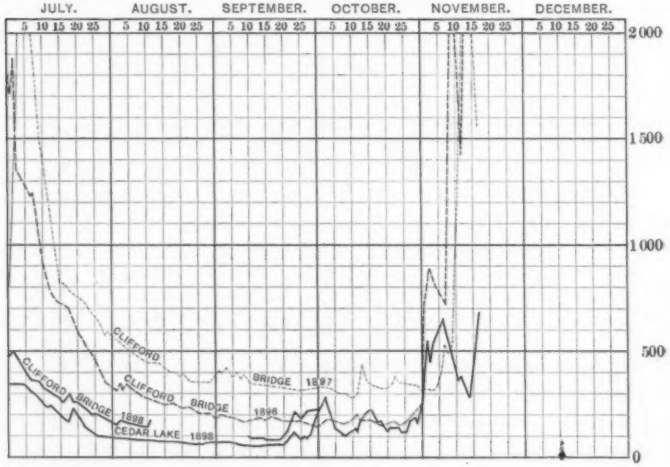

FIG. 5.

The author had no intention of drawing any general conclusions as to the application of Kutter's formula from the particular conditions prevailing in these discharge measurements any more than to point out the danger of using any formula for calculating the discharge in streams of this class. It is not always feasible or possible to take meter measurements, but it is nearly always possible to take submerged float measurements, which, if care is taken in selecting a locality where the cross-section is comparatively even for a short distance, the current slow, and the floats submerged close to the bottom, a fairly accurate measurement can be obtained. The difficulty in obtaining accurate data for calculation by Kutter's formula is often as great and sometimes greater than it is to take a submerged float measurement, and it has the further disadvantage of leaving the element

Mr. Noble. of the character of the stream to be judged by the engineer. This may also be said regarding the estimation of run-off from precipitation. It is generally easier, and far more satisfactory, to take measurements from the stream itself, particularly in a broken and uneven drainage basin. It would be necessary in a rough country to keep records at an almost infinite number of places, to determine the average rainfall, since it changes very radically in comparatively short distances. When a record of precipitation has been kept for some time in a certain drainage area, it becomes of considerable value to compare it with discharge measurements taken simultaneously at the same point.